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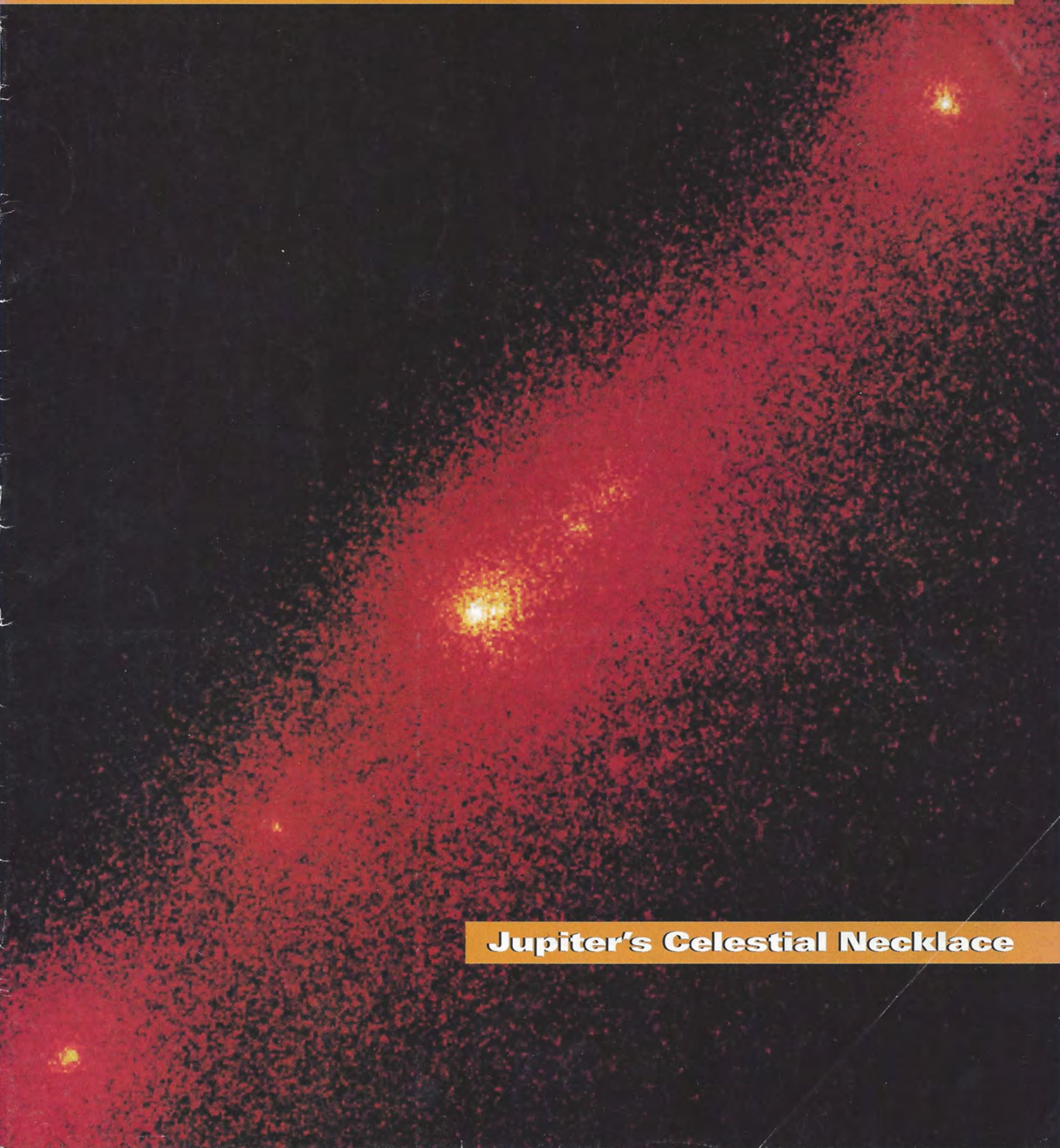

Jupiter's Celestial Necklace

On the Cover:
Skywatchers will be poised to observe the heavenly string of pearls known as comet Shoemaker-Levy 9 this July when it crashes into Jupiter's swirling atmosphere. This is an enlargement of an image captured by the Hubble Space Telescope (HST) on July 1, 1993, showing the region of the brightest nucleus of the comet, torn apart when it came too close to Jupiter in 1992. This "bright nucleus" is actually a group of at least four separate pieces. The span of this entire image covers about 64,000 kilometers (40,000 miles). North is at the lower right. Image: H.A. Weaver and T.E. Smith, Space Telescope Science Institute, NASA

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From The Editor

Yes, we have changed the design of *The Planetary Report*; your eyes do not deceive you. We have opened up space between lines of type and unified the design of our regular departments.

The endeavor of planetary exploration is, by its very nature, extremely challenging: To send robots and, when we are very daring, humans into hostile alien environments requires a willingness to undertake hard work. But, when new worlds are revealed for the first time, the hard work is worth the cost. Each planet explored widens our understanding of the universe around us.

It is our challenge, on the editorial staff of *The Planetary Report*, to make those discoveries accessible to all of our members. It is a difficult task to, for example, make an arcane point of celestial mechanics readily understandable. I know we don't always succeed. But, with your support, we keep trying.

With this redesign, we hope you will find it easier to "access" the information contained in our pages. As always, I ask you to let us know if we have succeeded.
—*Charlene M. Anderson*

Features

Departments

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Members' **Dialogue**

Members on Mars

I don't know if anyone else had this reaction, but I read Charlene Anderson's article, "Awaiting the First Explorers: Society Members' Names to Be Archived on Mars," through tears of joy.

Born without the means for a college education and without the physical constitution that would allow space travel, I have had to content myself with the knowledge that my tax dollars have ridden into orbit with *Mercury* and *Gemini*, and to the Moon with *Apollo.* To find out that my name will be on board the Mars landers when they arrive at Mars in 1995 means more to me than anyone will ever know.

Many thanks for the article and the good tidings it brought.
—JERRY L. BOCKMON,
Farmington, New Mexico

I have been a member of the Society for a good many years. During that time I've celebrated many space exploration triumphs and mourned many more space technology failures. I've felt personally humiliated by NASA. I've been reduced to watching *Star Trek: The Next Generation* for its pitiful ability to comfort with its visions of the future, but I have not sunk so low as to live in memories of past space program glories. Humans walking on the Moon is a painful thought, since it's never been equaled. I couldn't even open the November/December 1993 issue of the *Report* at first—the cover said it all. But when I finally read it and saw that members' names would be going to Mars on a microdot, I burst into tears. If only as an inscription on a microdot, I'm going to Mars.

Thank you.
—VALERIE CASSES,
Johnstown, Pennsylvania

As an old Arctic explorer, I'm thrilled by the fact that my name will be with those of other members of The Planetary Society on the Mars mission in 1994.

I was part of the past, now I'll be part of the future. Thank you, Planetary Society.
—JOHN ALTIERI, *Anaconda, Montana*

Spacecraft's Tough Job

I'm writing in response to David Budda's letter in the November/December 1993 issue of *The Planetary Report.* While VCRs may get "banged around" more than interplanetary spacecraft, they do not operate in the same conditions. Spacecraft have to endure temperatures well below room temperature and are subjected to magnetic fields, solar winds causing communication interference, particles traveling at tens of thousands of kilometers per hour, and even unknown conditions. In addition, spacecraft cannot be redesigned and "remarketed" with the relative ease, speed and low cost that consumer products are afforded.

As for the public's image of the space program, I think it has less to do with project failures than with the public's almost apathetic attitude toward science. Many are quick to call *Mars Observer* a failure, as if getting to Mars is a walk down the street. How many know how far away Mars is? Or even where Mars is? The unknown is too easy to criticize.
—MIKE KERNA, *Pittsburgh, Pennsylvania*

Take the Initiative

If the cause is to succeed, then we must think of alternative means with which to reach the goal. The Society's effort to further space exploration is the finest example of civilian power and initiative. So maybe it is time to let NASA fade away to be replaced by an organization supported by an endowment. The National Endowment for the Arts is a fairly successful group that has great lobbying power and influence. The private sector pushed by people who really care can do much more than befuddled politicians.
—JEROME A. MUSILLO,
Bayside, New York

The Coming Millennium

As a member of the New Millennium Committee, I believe that I am not alone in thinking that The Planetary Society is working on ideas that are critical to the future of humanity. Furthermore, as we are about to embark into the new millennium, our Society is eminently qualified to help define a powerful set of visions, plans and programs for our planet.

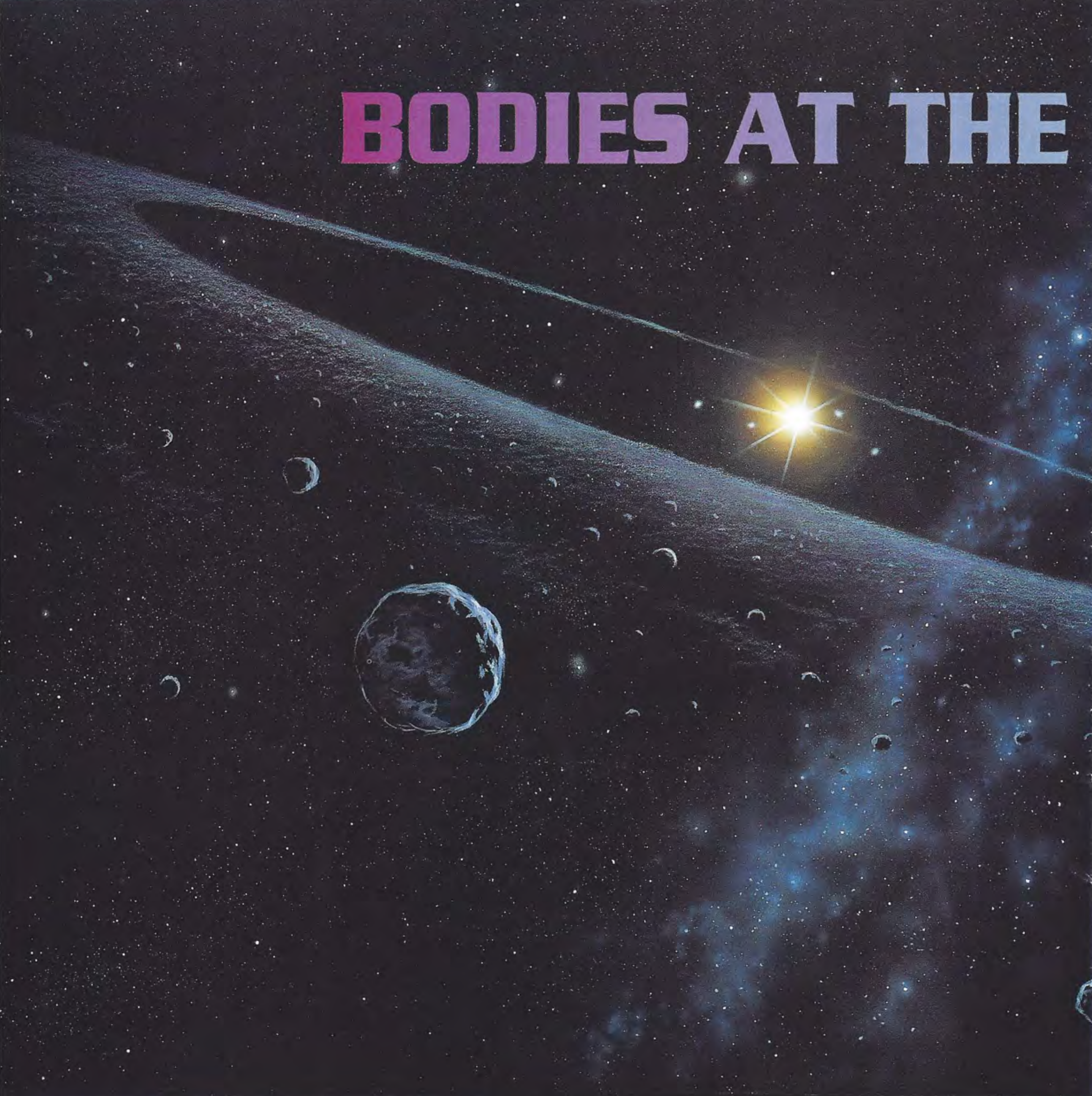
I propose that our Society's directors, staff, advisors and 100,000 members together develop a document laying out one possible road to a destination promising the possibility of adventure, prosperity, harmony, knowledge and hope. Ultimately, the world community will decide whether and how to act upon these ideas. At the very least, this document should stimulate the development of other ideas coming from other regions, interests or biases. The free interchange of ideas could form the basis for the agenda for the new millennium.

I see an urgent need now for a global, citizen-based, science-grounded independent leadership to come forward. I think The Planetary Society is one of the best qualified groups to begin that process.
—ABE GOMEL, *Montreal, Quebec*

Editor's Note: The New Millennium Committee is a group of individuals who have pledged $2,000 per year or have given donations of $20,000 or more in support of The Planetary Society's efforts to achieve its goals for the next century.

Please send your letters to Members' Dialogue, The Planetary Society, 65 North Catalina Avenue, Pasadena, CA 91106.

BODIES AT THE



The solar system just got a little bit bigger. The discovery of two objects beyond the orbit of Pluto has extended the heliocentric range of the planetary system (the distance outward from the Sun) and provided tantalizing hints that a large swarm of comets may exist in similarly distant orbits. This discovery has important implications for understanding both the origin of the solar system and the origin of the short-period comets.

The Big Break: Finding 1992 QB_1

Astronomers David Jewitt of the University of Hawaii and Jane Luu of Stanford University had been searching for five years for objects in distant orbits around the Sun. Their efforts were rewarded on the night of August 30, 1992, during an observing run on Mauna Kea, when they found a slow-moving, 23rd-magnitude object in Pisces. (The faintest star you can see without a telescope on a clear night far from city lights is 6th magnitude; 23rd magnitude is about 6 mil-

BRINK

by Paul Weissman

In the cold, dark reaches of the outer solar system, there may be a swarm of orbiting cometary nuclei. The pull of Neptune's gravity could begin to turn some of these lifeless bodies into short-period comets.
Painting: John R. Foster

lion times fainter.) Observations over the next few days showed that the object had to be very far from the Sun, about 41 astronomical units (an astronomical unit, or AU, is the average distance from Earth to the Sun and is equal to about 150 million kilometers or 93 million miles). For comparison, Pluto's average distance from the Sun is just over 39 AU.

At a distance of 41 AU, the object, officially designated 1992 QB_1, would be about 200 to 250 kilometers (125 to 155 miles) in diameter if it reflects sunlight in a similar fashion to the dark surfaces of cometary nuclei. Comets are dirty snowballs in space, icy conglomerates of primordial ices, dust and organic molecules that accreted in the distant reaches of the solar nebula. A large carbon content gives comets their very low reflectivity, and the organics often give them a reddish tint. Jewitt and Luu's observations showed that 1992 QB_1 was reddish in color.

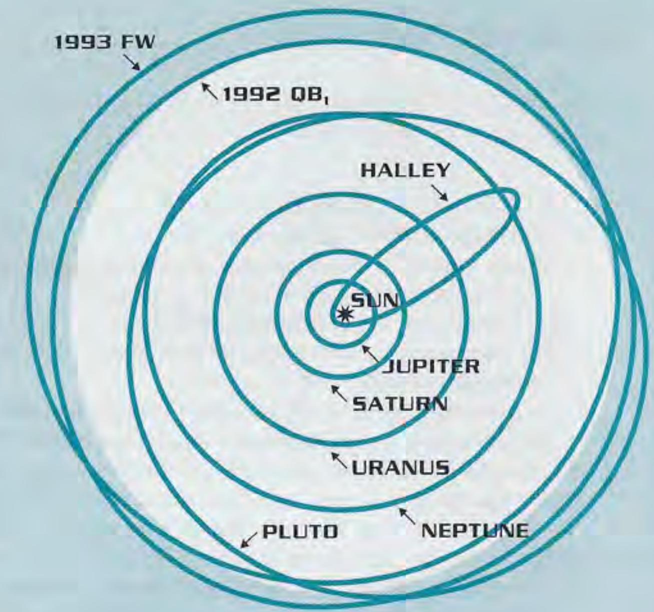
QB_1 was so far from the Sun, and moving so slowly, that it would take many months before an accurate orbit could be determined. Astronomers speculated that the object might be a giant long-period comet—one whose orbital period is greater than 200 years—on its way in from the Oort cloud, the distant spherical cloud of some 10^{12} to 10^{13} comets in orbits 3,000 to 100,000 AU from the Sun. Or it might be a comet traveling in a low-inclination, low-eccentricity orbit beyond the known planets, as had been suggested by astronomer Gerard Kuiper years before. (A low-inclination orbit is one in approximately the same plane as Earth and the other planets—the ecliptic plane—as they move around the Sun; a low-eccentricity orbit is close to circular in shape.)

By December, there were finally enough observations for a preliminary orbit determination. Brian Marsden of the Smithsonian Astrophysical Observatory found that 1992 QB_1 revolved around the Sun once every 290 years at an average distance of 44 AU, in a near-circular orbit inclined only 2.2 degrees to the ecliptic plane. The large distance, low inclination and low eccentricity matched Kuiper's hypothesis.

Kuiper's Hypothesis: An Idea Takes Hold

In a classic paper published in 1951, Gerard Kuiper of the University of Chicago speculated on the nature of comets and where they might have formed. Kuiper recognized that the icy nature of comets, pointed out by Fred Whipple of Harvard University the year before, required that they be formed in the outer reaches of the solar nebula, where temperatures were low enough to allow volatile ices to condense. Kuiper suggested that, as the giant planets began to grow in the midst of this swarm of icy bodies, some of the comets would have been gravitationally scattered to very distant orbits in the Oort cloud. But beyond Pluto, where no planet had formed, there was nothing big enough to scatter the comets. Orbit periods are so long beyond Pluto, and the density of material so low, that there simply was not enough time to grow a planet within the age of the solar system. Kuiper predicted that there would be a huge swarm or belt of comets in low-inclination, near-circular orbits beyond Pluto.

Kuiper's idea was taken up by other astronomers. In 1964 Fred Whipple suggested that a disk of comets beyond Pluto might perturb the orbits of the outer planets and comets. By studying the orbits of short-period comets having large aphelion distances (an orbiting object's maximum distance from the Sun)—comet Halley is an example—Whipple and colleagues showed that the disk could not total more than about 0.8 Earth masses of material if it was located at 40 AU, or 1.3 Earth masses if it was at 50 AU.



The inner edge of the Kuiper belt (darker shaded area) begins at about 42 astronomical units (or AU; 1 AU is the average distance from Earth to the Sun, equal to about 150 million kilometers or 93 million miles). The outer edge is unknown, but scientists suspect that it is at least 100 AU. 1992 QB1 and 1993 FW orbit the Sun just at the belt's inner edge and the planetary system's outer boundary.
Chart courtesy of Kevin Yau, JPL/NASA; drawn by B.S. Smith

As astronomers recognized that Pluto was not a very big planet and thus could not perturb the orbits of comets, they began to regard Neptune as the real outer boundary of the planetary system. In 1980 Julio Fernández of the University of Uruguay proposed that a comet belt beyond Neptune could be the source of the short-period comets. Unlike the long-period comets, whose orbits are randomly oriented on the sky, most of the short-period comets are in low-inclination orbits like those of the planets. The best way to get such an inclination distribution is for the comets to come from a source with that distribution. Also, because the Kuiper belt is much closer to the planetary system than is the distant Oort cloud, it would be easier for the planets to perturb the orbits of comets in the Kuiper belt down to short-period orbits, where we can observe them. Fernández calculated that the Kuiper belt would be 300 times more efficient than the Oort cloud in producing short-period comets.

The Dynamicists Debate

The key paper came in 1988 when Martin Duncan and colleagues at the University of Toronto showed that the Oort cloud was probably not the source of most of the short-period comets. Duncan and his colleagues ran computer-based simulations of cometary dynamics. They found that, when Oort cloud comets were captured to short-period orbits after repeated perturbations by the planets—that is, when their periods were reduced to less than 200 years—the comets still tended to have very high orbital inclinations. But when the comets came from a belt beyond Neptune—the Kuiper belt—they kept their low inclinations and looked just like the observed short-period comets. Duncan and his colleagues estimated that there would have to be between 10^8 and 10^{10} comets in the Kuiper belt for it to account for the observed number of short-period comets.

Cometary dynamicists excitedly debated these results. Some, such as Mark Bailey of the University of Liverpool, thought that high-inclination comets might be preferentially destroyed during their evolution to short-period orbits, leaving only the low-inclination comets to be observed. Because planetary perturbations are larger for the low-inclination comets (they have a higher probability of encountering one of the planets in the ecliptic plane), they evolve to short-period orbits faster than their high-inclination cousins. This shorter evolution time may be the key to their survival, while the high-inclination comets die out or disrupt before they can get to short-period orbits.

Some short-period comets, such as Halley and Swift-Tuttle (the parent of the Perseid meteor shower, which occurs in August every year), are in high-inclination orbits. Almost all of the high-inclination short-period comets also have relatively longer orbital periods, between 20 and 200 years. Dynamicists speculated that these comets came from the Oort cloud, whereas the low-inclination comets having periods of less than 20 years came from the Kuiper belt. Thus, the short-period comets may actually come from two entirely different sources.

Clues in a Disk

Other evidence for disks of comets like the Kuiper belt around other stars has come from studies of star formation. Astronomers have begun to image disks of material in orbit around protostars, young planetary systems in the process of formation. (If there are planets forming in these disks, they are too small or too far away to be seen with Earth-based telescopes.) These disks are typically several hundred astronomical units in diameter, much larger than our own planetary system. Could the solar system's original disk of material have extended to similar distances?

Data from the Infrared Astronomical Satellite (IRAS) suggested that such disks are fairly common. In 1983 IRAS discovered thermal (heat) radiation from dust clouds around many main-sequence stars (regular stars like the Sun) in the solar neighborhood. Some of the IRAS data indicated that the clouds of dust might be flattened disks. The largest of these was around a star called Beta Pictoris.

Astronomers Brad Smith of the University of Arizona and Richard Terrile of the Jet Propulsion Laboratory photographed the Beta Pictoris cloud by using a coronagraphic technique, in which the light of the central star is masked out. (A coronagraph is normally used to photograph the Sun's corona, or outer atmosphere, even when there is no solar eclipse occurring.) The image showed a thin disk of material seen edge on, extending up to 800 AU on either side of the star. Also, the IRAS data showed that the disk did not extend all the way to the central star but had a hole in the middle extending out to about 20 to 30 AU. This area may have already been swept clean by planets forming around Beta Pictoris. Estimates of the total mass of the Beta Pictoris disk range between 15 and 300 Earth masses of material.

In fact, our own planetary system could be surrounded by a disk like that around Beta Pictoris and we would not know it. IRAS observations in the ecliptic plane are dominated by radiation from the zodiacal cloud, the vast interplanetary cloud of dust from comets and asteroids. Because IRAS was most sensitive to warm dust, cold dust hundreds of astronomical units from the Sun would be very difficult for it to detect. Future infrared satellites with better sensitivity and resolution than IRAS will be required to settle the question.

Neptune the Perturber

Just about the same time that 1992 QB_1 was discovered, Harold Levison of Southwest Research Institute and Martin Duncan were studying the stability of orbits in the Kuiper belt. Pluto is too small to significantly perturb the comets, unless they come especially close to it, a far too rare event.

Thus, Neptune was the planet that was really controlling the comets' destiny. Levison and Duncan showed that even comets relatively distant from Neptune could be perturbed out of the Kuiper belt in less than a billion years. But beyond an average distance of about 42 AU, the orbits appeared to be stable—and 1992 QB_1's average distance was 44 AU. Thus, it had probably been in a similar orbit since the formation of the solar system.

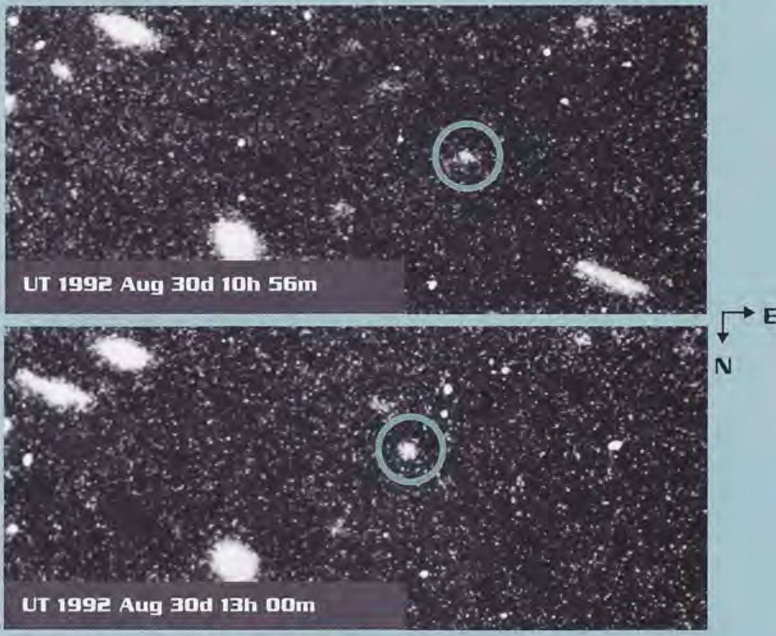
Company for 1992 QB_1

One object beyond Pluto was a tantalizing piece of evidence. But could it be a fluke, just one of a few bodies out there? Jewitt and Luu pointed out that they had searched less than 1 square degree of sky to find 1992 QB_1. Either objects like QB_1 were fairly common, or the observers had been extremely lucky to find this one object. Jewitt and Luu predicted that there should be about 10,000 objects similar to 1992 QB_1, and many more that were smaller, in the Kuiper belt.

While astronomers tried to comprehend the meaning of the new discovery, Jewitt and Luu were at the telescope searching for more Kuiper belt objects. In a surprisingly short time, in March 1993, their efforts were rewarded a second time with the discovery of 1993 FW. Once again, it quickly become obvious that the object was very far from the Sun. After several months, a preliminary orbit for 1993 FW showed it to be at an average distance just under 44 AU, with a low eccentricity and an inclination of only 7.7 degrees—again, a fairly low value. Interestingly, 1993 FW is about the same size as 1992 QB_1. More observations will be required before the orbit of 1993 FW is known precisely, but for the moment it appears to be the second member of the Kuiper belt to be discovered.

Jewitt and Luu were not done yet. In September 1993 they found two objects, 1993 RO and 1993 RP, at about 32 and 35 AU from the Sun, respectively. Soon, they had company. Iwan Williams (Queen Mary and Westfield College, London) and colleagues observing from La Palma in the Canary Islands found two more objects, 1993 SB and 1993 SC, at 33 and 34 AU, respectively. The four objects range from 22nd to 24th magnitude; because they are closer to the Sun than 1992 QB_1 and 1993 FW, which are both 23rd magnitude, they are probably of comparable size or somewhat smaller.

Also, because all four objects are in orbits much closer to Neptune's orbit, their orbits may not be stable over the age of the solar system. These four objects may have been perturbed out of the Kuiper belt and are now beginning the evolution toward short-period orbits. However, there is only about a 10 to 15 percent probability that they will make it all the way to short-period status. The more likely eventuality is that they



The slow motion of 1992 QB_1 (circled) can be discerned relative to distant, fixed galaxies. These discovery images were captured the night of August 30, 1992, by David Jewitt and Jane Luu using the University of Hawaii's 2.2-meter telescope. The elongated object that moves from lower right in the top image to upper left in the bottom image is the trail of a main-belt asteroid that was moving during each exposure.
Images courtesy of David Jewitt, University of Hawaii

will be dynamically ejected from the solar system by a close encounter with one of the giant planets.

Unlocking the Secrets in Primordial Ice and Dust

All the discoveries cited here have gone a long way in providing evidence for a cometary swarm beyond Neptune. That swarm, which may extend out to several hundred astronomical units from the Sun and contain many tens of Earth masses of comets, is a remnant population of primordial icy bodies from the solar nebula. They preserve the cosmochemical record of the original interstellar gas cloud out of which the solar system formed. Some of those bodies find their way to short-period comet orbits where we can observe them. And if we could go out and study one of those objects at close range, or even bring a sample back to Earth for detailed analysis, we might unlock some of the secrets of how our solar system formed.

The European Space Agency has been working on a mission called *Rosetta*, to be launched in 2003, which will rendezvous with a short-period comet and perform onboard analyses of cometary materials. *Rosetta* may carry a package of instruments, perhaps provided by NASA, that will land on the comet to make direct measurements of the composition and physical properties of the nucleus.

Like its namesake, *Rosetta* will unlock the secrets of our past. Gerard Kuiper would have been pleased to see where his speculating about comets has led.

Paul Weissman is a planetary scientist at the Jet Propulsion Laboratory, specializing in studies of the physics and dynamics of comets, and their interactions with the planetary system. He is also a member of the Near Infrared Mapping Spectrometer team on the Galileo *mission to Jupiter.*

Jupiter Watch: The Celestial

It could be a once-in-a-thousand-lifetimes event. It could blow a hole in Jupiter's atmosphere, changing the planet's face for millennia. It could be the biggest celestial show in human history. Or, for those of us from a small blue planet hundreds of millions of kilometers away, it could be a dud.

No one knows for certain what will happen in July when comet Shoemaker-Levy 9 collides with the planet Jupiter. We do know that it will be an unprecedented event. Whatever happens, The Planetary Society will be working to make sure that the greatest possible number of people around the world share the excitement of this extraordinary occurrence.

Here's a little background on comet Shoemaker-Levy 9. On March 25, 1993, during an observing run at Palomar Mountain Observatory in California, Carolyn Shoemaker noticed what appeared to be a "squashed comet" on a photograph she had exposed while working with her husband, United States Geological Survey planetary scientist Eugene Shoemaker, and amateur astronomer David Levy. The team immediately notified a colleague at the University of Arizona's Lunar and Planetary Institute, James Scotti, who uses the Spacewatch telescope at Kitt Peak Observatory. With this larger telescope, equipped with sensitive charge-coupled devices (CCDs), he was able to determine that the object was actually a string of comet fragments. (See page 28 of the July/August 1993 *Planetary Report.*)

Excited by the discovery, astronomers around the world trained their telescopes on the object. With a series of positions recorded, orbital analysts were able to plot its orbit and predict the path of the comet both backward and forward in time.

They learned that the comet is actually in orbit about Jupiter, not about the Sun, as are most of the comets we know of. This intriguing finding indicates that comet Shoemaker-Levy 9 may have begun life as a very small, volatile-rich satellite of Jupiter, as a so-called Trojan asteroid locked into Jupiter's orbit or as a comet captured by the planet's great gravitational attraction.

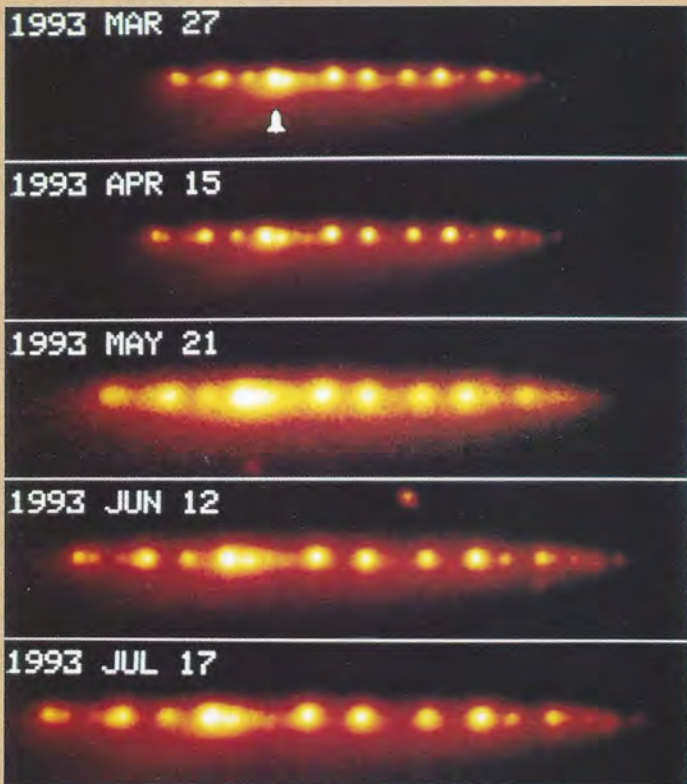
Going back in time, the analysts determined that in July of 1992 the unlucky comet passed too close to the giant planet, coming within its Roche limit. (Named for 19th-century French mathematician E.A. Roche, this is the distance from the planet within which a small, solid object will be torn to pieces by tidal forces from the planet's gravity.) This close encounter ripped the comet into at least 20 fragments, which astronomers now refer to as a "necklace" or a "string of pearls."

Moving forward in time, the analysts made the most exciting discovery of all: On or about July 21, 1994, comet Shoemaker-Levy 9 is doomed to collide with Jupiter.

We don't yet know what we will see when the comet fragments encounter the largest planet in our solar system. Early estimates had put the size of the biggest fragment at about 10 kilometers (6 miles) in diameter—the size of the object that struck Earth 65 million years ago and is believed to have wiped out the dinosaurs. But James Scotti and colleague H. Jay Melosh now estimate that the comet was less than about 2.5 kilometers (1.5 miles) in diameter before its breakup,

Necklace Breaks

by Charlene M. Anderson



Left: These composite images of comet Shoemaker-Levy 9 were captured over five months in 1993. David Jewitt and Jane Luu obtained them using a charge-coupled-device camera with the University of Hawaii's 2.2-meter telescope atop Mauna Kea. The images have been corrected for the changing distance to the comet and show the real expansion of the "string of pearls" over time. A total of 21 components are visible in the digital images; some are lost in the photographic reproduction here. Images courtesy of David Jewitt, University of Hawaii

Left: This image was taken with the University of Arizona's Spacewatch camera. Although not discernible here, the bright "streak" near the center contains many individual nuclei with their comae and tails. Light scattered from fine dust particles extends for large distances beyond the region of the streak. Image: Jim Scotti, University of Arizona

Above: Here's how the comet looked on March 28, 1993, from the Steward Observatory's 2.3-meter telescope at the University of Arizona. This close-up of the nuclear train shows about 12 individual nuclei embedded within the coma. The bright spot at the left is an unnamed star. Image: Wieslaw Wisniewski, University of Arizona

Left: Like a series of multimegaton bombs, comet Shoemaker-Levy 9 could sow a row of mushroom clouds on the face of Jupiter. Painting: Michael Carroll

which has considerably reduced the estimates of the energy that will be released on impact with Jupiter.

Still, it could be an impressive event. The fragments will hit Jupiter's atmosphere at about 216,000 kilometers (135,000 miles) per hour and vaporize, possibly causing the eruption of plumes of debris from its deep, hidden recesses.

Unfortunately, this will be hidden from observers on Earth. The comet's trajectory will carry it into the far side of the planet. From Earth, we will be able to see the effects of the collisions only indirectly—for example, from light reflected off Jupiter's large Galilean satellites.

The string of explosions may disrupt Jupiter's banded atmosphere. Although the impacts will occur on the far side, the affected regions will swing into view in a few hours due to the planet's rapid rotation, and we may be able to see the atmospheric effects. We may even witness the birth of a new Great Red Spot.

Scientists will continue to refine their calculations to predict what observers can expect to see next July. In the meantime, we have begun to get ready.

Under the title of "Jupiter Watch," we are planning several different types of activities:

- Setting up a worldwide network of observers, to ensure that some telescope on Earth is always pointing toward Jupiter during the string of impacts.
- Establishing liaisons between professional and amateur astronomers so that the amateurs can make valid contributions to understanding the impact events.
- Publishing Jupiter Watch observers' guides so that viewers can get the most out of this rare opportunity.
- Providing video links from telescopes to auditoriums, classrooms and television stations so that even those without access to a telescope can watch the collisions as they happen.
- Organizing Jupiter Watch parties around the world to encourage people to go outside, look up into the sky and see something that will probably never occur again during their lifetimes.
- Holding a gala party in Washington, DC, to honor the comet's discoverers—and to celebrate another historic event that occurred 25 years almost to the day before the Jupiter impacts: the *Apollo 11* landing on the Moon.

These projects will be just the beginning of the Society's Jupiter Watch. The *Galileo* spacecraft is now on its way to the jovian system, and it will arrive 17 months after the comet fragments. The spacecraft should be able to see the impacts directly and detect the effects of the explosions through several of its instruments, then relay the data back to Earth. Between the impact date and *Galileo*'s arrival at Jupiter, we will continue to build support for and raise awareness of planetary exploration with an ongoing series of special events.

We have set ambitious goals for Jupiter Watch, and we will need your help to achieve them. If you are interested in helping with any of our activities, please contact us by writing: Jupiter Watch, The Planetary Society, 65 North Catalina Avenue, Pasadena, CA 91106.

Charlene M. Anderson is Director of Publications of The Planetary Society.

A Rover's Journey:

Linking Two Worlds

BY GEORGE POWELL

RIGHT: ON THIS MORNING THE CLOUDS PARTED BRIEFLY TO REVEAL THE TOP OF TOLBACHIK VOLCANO ON THE KAMCHATKA PENINSULA. THE RAINCOAT-CLAD MARS ROVER SITS ON THE VOLCANO'S FLANKS, READY FOR A DAY OF TESTS.

PHOTO: GEORGE POWELL

As the airliner's captain announced our final approach into Moscow's international airport on the morning of August 19, 1993, I pulled out a fax I had slipped into my notebook some 16 hours earlier as I was leaving the Space Dynamics Laboratory at Utah State University for the Salt Lake City airport. It was from Charlene Anderson, editor of *The Planetary Report*. She informed me that part of my job on this trip to Russia was to write an article for the magazine. The fax was filled with admonitions to *try* to take good photographs (no backs of heads, no fingers in front of the lens, and so on). It ended with these words: "*Be personal.* You're sharing the excitement of these tests with the members who paid your way."

Well, here goes. What happened to me in Russia certainly was an adventure, and I'd like to think that this story will bring you a taste of what it was like to be part of the Russian team, and to watch as the rover began to move in response to a controller working a computer keyboard thousands of miles away.

I had been sent to Russia as The Planetary Society's representative at tests of the Mars Rover, a critical part of the Russian *Mars '96* mission. The rover will provide a mobile robotic platform for studies of the martian terrain.

In 1992, the Society sponsored an expedition to Death Valley, California, to test the rover's mobility and navigational capabilities and to check out the overall system. (See the November/December 1992 and January/February 1993 issues of *The Planetary Report.*) For these follow-up tests, we were going to the forbidding volcanic terrain of the Kamchatka Peninsula, and we would concentrate more on navigation and on testing a French stereo video system.

We were also going to conduct a major experiment in telepresence: A team of scientists and engineers in California would attempt to operate the rover through a satellite telephone link. We wanted to investigate whether the developing computer technologies of telepresence and virtual reality could be used to explore Mars.

Operating the rover from California would be a good simulation of the planned method of operation of the vehicle on Mars, although it would lack the Earth–Mars communications time delay of about 20 minutes. The operators in California would not know the test site beforehand; they would have to gather data strictly from instruments on the rover. This scenario would provide the first realistic test of the remote control of the Russian Mars Rover.

My main responsibility on the Kamchatka expedition was to supply the communications link between the United States and Russia. Thus, I was carrying a rented $45,000 Inmarsat mobile communications ground station in an 80-pound metal suitcase. I was also lugging a smaller metal suitcase, weighing only 70 pounds, that held a laptop computer and other test equipment. I had one piece of personal luggage.

This was my first trip to Russia, and I was relieved to find my good friend Katya Linkina waiting for me at the airport. I'd met Katya at Planetary Society headquarters just before the Death Valley expedition, and this year she was in charge of organizing the tests in Kamchatka. She's a scientist at the Russian Institute for Space Research, which is known by its Russian initials as IKI. It is one of three centers working on the *Mars '96* mission; the other two are the Babakin Center in Moscow, responsible for building the spacecraft, and the Mobile Vehicle Engineering Institute (VNIITransmash), which designs the Russian rovers, in St. Petersburg.

I spent four days with the Russian team members—10 scientists and engineers from IKI and VNIITransmash—checking out the equipment, making sure that the various components (the Russian rover, the French cameras and the American communications link) all worked together. Then we packed up the equipment and began our journey to Kamchatka.

It was a nine-hour, nonstop flight to Petropavlovsk-Kamchatskii, a city of about 300,000 people on the Kamchatka Peninsula. The city had previously been off-limits to foreigners because it was the location of an extremely secret Soviet military base. As we landed, I got my first close-up look at a MiG fighter, parked on the tarmac.

At the hotel, I rendezvoused with two other Americans, whose participation in the tests had been suggested and arranged for by The Planetary Society: Michael Sims from NASA Ames Research Center and Carl Ruoff from the Jet Propulsion Laboratory. They told me that I'd better get used to cold showers. It seems that Petropavlovsk has a centralized hot water system to supply the entire city, and there was no fuel for the plant.

The next day, at 8:00 a.m. sharp, we all met in the hotel lobby, ready to begin a 10-hour drive to Kosyrevsk, the small town near our first test site. We were told that one of the trucks had a water pump problem and there would be a short delay. At 6:30 p.m., we finally loaded up our gear and set out. We traveled through the night, stopping only for rest, vodka and a midnight bonfire.

The Russians have a very impressive test facility at Kosyrevsk. The main house has many rooms, each with two or three beds. There is one bathroom with running water and a shower. A wood-fueled water heater supplies both the bathroom and a kitchen. There are three other small houses for sleeping.

The main kitchen is in a separate building about 40 yards from the main house. The Russians had hired a cook from the area to prepare three meals a day for us. We had fresh salmon, piles of vegetables and wonderful Russian potatoes. Though I did have some problems with the fish-head soup, I hadn't eaten so well in a long time.

On our first day in Kosyrevsk, we assembled the rover chassis and fixed some minor problems with one of the wheels. We worked into the evening so that we would be prepared for our first test with the US, scheduled for 9:30 a.m. the next day. Fortunately, this test would be held near the house in Kosyrevsk.

We were only a few minutes late in beginning the test, and everything went well. The team in the US was able to direct the rover, giving it simple commands, such as forward, right, left. More important, they were able to take video images of the rover's surroundings. There were a few miscommunications, but by the end of the one-hour test everything was running smoothly.

After lunch we headed out to find a site where we could test the rover over rough terrain. One of our trucks had returned to Petropavlovsk, so all 13 of us, the rover, the power generator and all the other equipment were stuffed into one truck. Getting to know the other team members was now very easy.

After a 30-minute drive, we stopped in what looked like a nearly dry riverbed, lined not with white sand but with black ash that had been washed down from the Tolbachik volcano, 50 kilometers (30 miles) away from us. We found a good test site, set up the rover and took a few stereo images. I planned to send these images to the US in the morning so team members there could use them to produce the three-dimensional images needed for the virtual reality environment.

The following morning, I was the first person up. It was 6:00 a.m. and I had to send the stereo images to the US before we moved out to the test site. As I set up the satellite link, I sighed in relief, for it was the first clear day we had seen in Kamchatka. But my optimism was short-lived.

For the next three hours, I tried to establish a satellite modem link with the US, and I couldn't get anything to work. I finally had to quit trying so we could leave for the test site. We arrived late and had some problems with the equipment.

Editor's note: Back in balmy Southern California, the US portion of the team had gathered in an air-conditioned

Above: The rover's camera "eyes" are on top, so the Russians had to make a visor to protect its vision, and a raincoat to cover the control and navigation equipment. Photo: George Powell

Left: The team had to create obstacles for the rover in a new test area after a storm flooded the dry riverbed (photo above) they'd planned on using.

Right: The Kamchatka team waits patiently as the group in Huntington Beach, California, controls the rover. Photos: Carl Ruoff

facility in Huntington Beach owned by the McDonnell Douglas Corporation. A "Mac Dac" team, led by John Garvey, was working with us and with NASA Ames to test telepresence as a way to navigate and control the rover.

This was our first official test day, and we had invited high-ranking managers, engineers and scientists from around the world to witness the tests. While George was struggling in frigid Kamchatka with the equipment, we were drinking cold sodas, eating chocolate chip cookies and wondering where our wandering engineer could be.

We were running about an hour late when I made the first communications link with the US. It was only a partial link and they were receiving garbled data. To make things worse, I knew that people from around the world were watching to see how we would do. We finally found, and solved, the problem—it was an obscure software setting on the US side of the link. We managed to transmit a few images before the rover was scheduled to begin other testing. Then it began to rain. We packed up all the gear and drove back to Kosyrevsk.

It rained through the night, and I woke up several times, wondering if it was ever going to stop. Finally, it let up at daybreak. We were all a little quieter at breakfast, wondering if the day would be a repeat of the day before.

When we got to the test site, we found that our broad riverbed had been engulfed by a raging torrent. We had to find another site. We managed to find a still-dry streambed,

Above: This was the camp on Tolbachik. The building on the left was the kitchen and dining hall; on the right were the sleeping quarters. The scraps of firewood littering the ground explain how the team cooked and kept warm. Photo: Carl Ruoff

Above: As the team worked with the rover, George struggled (successfully) to overcome a software problem that was garbling communications between him and the group at McDonnell Douglas. Photo: Carl Ruoff

but it was mostly uninteresting sand and ash. We had to gather up boulders to construct a worthy test bed.

We were about an hour behind schedule when I made my first contact with the group in California. They were very happy to hear my voice.

I hooked up my laptop computer to the Inmarsat system. The computer modem connects to a small control box on the Inmarsat terminal. The box has many function keys and a 10-key pad.

The function keys allow the user to scroll through menus to select such things as longitude and latitude, satellite and ground station. The terminal, in turn, tells the operator where to point the parabolic antenna. Then the user can make either a voice call or a modem call. All in all, it is quite simple.

Once the link was established, the computer in Huntington Beach was able to talk to my laptop in Kamchatka. The laptop simulated the flight computer on the rover. The plan was for the US team to issue commands to the laptop, and it in turn would control the wheel movements, acquire images from the cameras and take measurements of the rover's position.

On this day the modem link worked perfectly, and I could see our months of preparations paying off. Viacheslav "Slava" Linkin, chief scientist on the project, was in California supervising the test, along with Planetary Society Executive Director Louis Friedman. The team there studied the images returned by the rover, analyzed the terrain and decided how to move the rover. When the course was laid out, Greg Loboda, a McDonnell Douglas engineer sitting at a computer terminal in Huntington Beach, executed the command.

Over in Kamchatka, we sat and watched the rover move forward, turn and avoid obstacles. We were not in direct communication with the US at this time, and we were impressed as we watched the rover navigate the terrain. We could see how the US operators were feeling their way around the boulders. It's too bad I won't be able to watch the rover explore Mars from a similar vantage point!

The tests went on for about two hours, and then I had to break the computer link so that the rover could move on to other tests scheduled by the Russian engineers.

On August 31, we began our move out onto the flanks of Tolbachik volcano for more tests. The main road had been washed out in the rainstorm. We had hoped to travel to our camp by helicopter, but couldn't get one. We ended up taking the long way round, a four-hour ride. The entire team, all the technical equipment, sleeping bags, pots and pans, and food for three days were piled into one truck. It was all we could do to keep from being buried alive as the truck lumbered across the landscape.

Rain poured down most of the way, but we finally made it to the volcano. In every direction we looked, there were cinder cones. Four kilometers away were two cinder cones created in 1975. We visited them on another day and could still feel the heat and smell the sulfur.

The camp consisted of one large, two-storied structure used for sleeping, a small separate kitchen and dining hall, a Ping-Pong room and an outhouse. Windblown ash had covered up the lower doors, and we had to shovel it away to get into the buildings.

Weather on the volcano was very erratic, with wind and rain coming and going several times a day. With this in mind, we outfitted the rover with its own plastic raincoat. One of the Russians made it a hat to protect the cameras.

The test site was about 150 yards from the camp. It was filled with obstacles that the rover could not overcome, and there were only two possible paths around them. The site was much more treacherous than the *Viking* landing sites on Mars, and the next day's test would be the most difficult we had yet attempted.

That night we lay swathed in mummy bags on our plank beds, and we listened to the wind howl.

The morning broke picture-perfect. We could actually see the top of Tolbachik. After breakfast we set up for the tests. I called the US half an hour before the telepresence tests were scheduled to begin and told them that we'd made it to the volcano and things were going well. Greg told me that the room at McDonnell Douglas was packed with people, including members of the press. That worried me a bit because the test area was much more difficult than anything we'd attempted so far.

Editor's note: George was right to worry: CNN was taping our end of the telepresence test as it happened. Within a few hours his success—or failure—would be broadcast around the world.

The first command the US team sent to the rover was

Stretching the Limits of Reality

The term *virtual reality* is used to describe highly interactive, three-dimensional computer graphics systems that give users the illusion of being immersed in a simulated environment. This simulated environment is variously referred to as a virtual environment or a virtual world. Simulators used in training airplane pilots and space shuttle astronauts employ virtual reality to make trainees feel as if they are actually airborne.

Users can enter many of the newer virtual environments by means of systems that require goggles having a small display screen for each eye (to simulate three-dimensional effects) and a glove equipped with sensors that detect the user's movements and translate them into the person's motion through the virtual world. For instance, to move forward in a virtual environment, users simply point forward. The computer then updates the screens' displays to simulate movement through the three-dimensional environment.

Telepresence refers to an application of virtual reality principles using real images instead of computer-generated graphics. Telepresence projects the human sensory apparatus into a remote location. The tests George Powell describes here use telepresence technology. The stereo cameras on the rover captured scenes of Kamchatka that were then transmitted to distant Huntington Beach, California, and displayed for the viewers.

Both virtual reality and telepresence will probably play a large role in future planetary exploration. NASA has been developing a virtual environment simulator that uses data from flybys like *Voyager*'s to let the user "fly" over a planet's surface. Scientists and students may eventually be able to work with actual data and carry out experiments on a remote planet without ever leaving their offices and classrooms. In the future, explorers may be able to use virtual reality techniques to see not only from the United States to Kamchatka but also from Earth to Mars. We may soon have missions to Mars that are controlled—virtually—through the vital link of telepresence.

At The Planetary Society, we are excited by the possibilities these technologies offer. We are working with our partners in the rover project on the idea of mobile virtual reality stations that may one day give people around the world the experience of driving a rover across another planet. We can envision schoolchildren everywhere using their personal computers to link up with a spacecraft on Mars.

The confluence of computers, robotics and the coming "information superhighway" will change the way we conduct planetary exploration. As yet we can only imagine this future, but The Planetary Society is working hard to help shape it.

—Charlene M. Anderson

a request for stereo video images. As the images were being relayed over the satellite, which took about 10 minutes, clouds began to roll in over the site. Within those 10 minutes, visibility dropped to 20 meters (about 65 feet).

We watched as the rover moved forward 1 meter and started to take another set of images for the US team. Then it began to rain. The laptop computer was sitting on a portable table, and we covered it with a canvas tarp to keep it dry. The rover's raincoat seemed to be working pretty well.

The rover turned right and started taking another image, and the rain became intense. I looked over to the satellite ground station and water was pouring off it like a waterfall. I wondered how long it would be until something shorted out.

The US team was navigating past the obstacles extremely well. As the weather got worse, I was amazed that all elements of the rover system continued to operate.

There were only 25 meters (about 80 feet) of cable between the cameras on the rover and the laptop computer linking it to the US. The rover was negotiating the terrain more quickly than we had anticipated, and we realized that the cable was not going to be long enough.

So, someone had the bright idea that we could pick up the table the laptop was on and move it closer to the rover. With luck we could do it without disconnecting the power or disrupting the communications link. The US people wouldn't even know we'd moved the table, right?

We picked up the table and water began to splash off the canvas tarp in big waves. We had actually managed to move the table close to the rover and set it down when someone bumped the power cord, and the link went down.

Within a few minutes we were able to reestablish the link. The US team resumed command of the rover and operated it for another hour.

Editor's note: Back in California, we were having a great time. Slava Linkin and the Planetary Society–Mac Dac team quickly got the knack of driving the rover and gained confidence as they drove it across the volcanic Kamchatka terrain.

As the images came, we relayed them to a team of geologists at Brown University in Rhode Island and to the telerobotics scientists at Ames Research Center in Mountain View, California. The Brown geologists were interested in seeing if they could correctly analyze the landscape from the rover images. The Ames scientists were taking the stereo pairs, running them through their virtual reality program and transmitting them back to us in Huntington Beach.

There, a Silicon Graphics workstation displayed a three-dimensional map of the terrain through which we could "drive" the rover. Using the first pictures returned from Kamchatka, the Ames people even created a limited virtual environment complete with a virtual rover. We could watch the rover as it moved or view the virtual landscape through the rover's eyes.

With state-of-the-art computers and software to play with, trays of cold cuts and bowls of fresh fruit to eat, and a sunny California day awaiting us outside, we could ask for nothing more than a few extra minutes with the rover.

But the Kamchatka team signaled us that the rain was getting heavier and the temperature was dropping. There was one more picture they thought we could get before we declared the 1993 rover test program over.

It took a few minutes for the computer to process the last image, and then we saw our compatriots in Kamchatka,

The Kamchatka expedition team. Back row: Igor Blokchintzev (I), Alexei Gasperovich (I), Carl Ruoff (J), George Powell (U), Valeri Gromov (V), Vladimir Nosik (V) and Alexander Popov (V). Middle row: Leonid Kasperovich (I), Konstantin Belovsov (I), Michael Sims (N) and Alexander Pomin (V). Front row: Marina Kolesnik (I), Katya Linkina (I) and Nikolai Kuznetsov (V). *Image: Mars Rover* *KEY— I: Russian Institute for Space Research; J: Jet Propulsion Laboratory; U: Utah State University; V: Mobile Vehicle Engineering Institute; N: NASA Ames Research Center.*

cold, wet and huddled together in front of the rover's camera. (See photo, above.) They had done a great job and, over the computer link, we thanked them.

Our last test was finished, and we realized that the expedition had been a complete success. The US side of the team had controlled the rover through teleoperation, under conditions closely simulating a real Mars mission. The remote operators were able to understand the rover's immediate environment by using images and telemetry relayed by satellite, and they then successfully navigated through difficult terrain. We couldn't have asked for more from these field tests.

There is still a lot of work to be done before the rover is ready for Mars. The Russians are proceeding on an aggressive schedule, and their progress is impressive.

The entire team, both in California and in Kamchatka, worked incredibly hard to achieve this success. Through the support and contributions of Planetary Society members, an important step was taken in exploring the worlds around us.

As for me, I only had to get home, and that trip proved more of an adventure than anything that had happened so far. Let's just say that I did make it home to Logan, Utah, on September 6. My luggage—with all that very expensive electronics equipment—did not arrive until the next day.

Editor's note: Our final day of testing was so extraordinarily successful that the entire Planetary Society–McDonnell Douglas–NASA Ames–IKI team, along with press people who'd gathered to watch, were stunned by what we'd accomplished. We had proven that, in partnership with robots and computers, we can extend our reach and our vision to distant continents, and, using the same technology, we will eventually be able to reach and see even further—to distant worlds.

George Powell is an electronics engineer at Utah State University's Space Dynamics Laboratory, and has been working for The Planetary Society on the Mars Rover and on the Snake for the Mars Balloon for six years.

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Newton's Clock: Chaos in the Solar System

By Ivars Peterson; W.H. Freeman, New York, 1993, 317 pages.
Retail price: $22.95
Member price: $20.00

Rough winds blew Columbus' threadbare armada to Jamaica in 1504. Since his crew had pillaged the island on an earlier visit, Columbus was in a bind. He had to convince the understandably hostile islanders to help provision his ships.

Desperate, he consulted his navigational tables and saw that a lunar eclipse would soon occur. Gambling that the tables were accurate, he gathered the island's leaders together and warned them that if they did not help him, the Moon would disappear from the sky the next night. There was an eclipse, and the rest is history.

In *Newton's Clock,* Ivars Peterson includes Columbus' gamble in his two-thousand-year sweep of efforts to predict celestial movements. Along the way he describes some of the instruments used to track the planets, from a first-century BC mechanism found by deep-sea divers off the Greek island of Antikythera in 1900 to the Digital Orrery—a computer built in 1984 that could trace the orbits of planetary bodies 100 million years into the past or into the future.

Peterson is eager to explain how computers like the Digital Orrery have revolutionized astronomy. For example, they have been instrumental in solving old problems, such as the long-standing mystery of the Moon's irregular movement, and, with data from the *Voyager* missions, new problems, such as the odd movements of Hyperion, "a frigid misshapen chunk of ice and rock orbiting Saturn," which tumbles in its orbit instead of spinning like a top.

Peterson paints colorful word-pictures about historical greats, like Kepler, who had to interrupt his work in 1617 to help his mother, who was on trial for witchcraft.

An excellent guide to mathematics as well as to mathematicians, Peterson comments that Newton was too brilliant in the *Principia* because he convinced generations of astronomers that the universe is both coherent and predictable.

This is where chaos theory enters the story. Chaos is as hard for the general public to grasp as the math at the core of Newton's theory. But just as Newton's public worshipped his theory without understanding it, many people today like the idea of chaos theory but understand only one part of it: the concept that even within a seemingly regular system some things just cannot be predicted.

In *Newton's Clock,* Peterson shows how chaos theory explains the irregularities that stymied Newton, such as the Moon's tilting and wobbling as it is pulled by both the Sun and Earth. And he shows that the Moon and Hyperion can both be understood today even though their celestial locations in the distant future cannot be predicted.

This brings him to another question, which he does not answer. Is the solar system balanced so precariously—with just the right number of planets—that a major perturbation would blow it all apart? Or is it resilient enough to absorb unpredictable events?

Peterson leaves us with the disquieting thought that the future of the solar system is as unknowable in the very long run as is the future of the universe.

For those who love mathematics, *Newton's Clock* will be a treat. And for those who usually skip the equations, this excellent read will leave them more mathematically savvy than they ever thought they could be.

—Reviewed by Bettyann Kevles

Still Available:
The Evening Star: Venus Observed

By Henry S.F. Cooper, Jr.
One of the best space science writers of our time chronicles the *Magellan* mission to Venus.
(Reviewed September/October 1993.)
Retail price: $22.00
Member price: $19.00

Tales of the Earth: Paroxysms and Perturbations of the Blue Planet

By Charles Officer and Jake Page.
Reader-friendly, with just the right mix of solid data, anecdote and humor, this well-illustrated volume examines some of the cataclysmic events in Earth's tumultuous history.
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World Watch

by Louis D. Friedman

Washington, DC—The United States Congress took final action on the NASA appropriations bill two weeks after the start of fiscal 1994. Of major interest to Planetary Society members are the two new starts for planetary missions. Both are in the Discovery program and are subject to a $150 million limit on development cost (launch and operations not included). Sadly, however, Congress canceled the High-Resolution Microwave Survey (HRMS), NASA's entry in the Search for Extraterrestrial Intelligence, almost one year to the day after the project began its observations.

One of the planetary new starts is MESUR Pathfinder, which will send a small lander with a 9-kilogram microrover to Mars in 1996. The mission is a technological precursor to the full MESUR (Mars Environmental Survey) mission, which will put a number of small landers on Mars.

The other planetary new start is the Near Earth Asteroid Rendezvous (NEAR). Its launch is scheduled for February 1996. NEAR's primary mission is a close-up investigation of the asteroid Eros, but additional asteroid flybys, including one to Iliya, are planned. A third mission approved in concept, with $10 million initial funding, is a to-be-defined *Mars Observer* recovery mission, presumably with a 1996 launch also.

Washington, DC—The administration's space station budget was approved, although some restrictions were put on expenditures pending a full report on the station redesign and the use of Russian capabilities. Space station *Alpha* (the name *Freedom* has been officially dropped by NASA, along with its design) includes a modular design and development plan able to accommodate the Russian *Mir 2* or a US module should the agreement to incorporate *Mir 2* fail.

The Planetary Society was invited to testify before both the Senate and the House committees during the debate on the space station. We were particularly asked to comment about the implications of the new Russian role. The full transcript of the Society's statement before Congress can be obtained upon request.

The administration's new program is a three-phase approach. The first phase includes several shuttle–*Mir* rendezvous and American astronauts flying extended-duration missions on *Mir* (see next report). The second phase calls for the development of a US human-tended facility connected to a *Mir* module, and the third phase moves on to the permanent-presence capability and adds the European and Japanese modules.

This phased approach permits a "go as you pay" philosophy, advocated by the Augustine committee in 1990.

Moscow—In January 1994, Russian cosmonaut Valeriy Polyakov is to begin an 18-month flight on *Mir*. This will be the longest flight ever by a human in space. A Russian news report stated that the rationale of the upcoming flight was to gather data for "a flight for Mars, which could be carried out through the joint efforts of Russia and the United States." It is noteworthy that the article was written in old-style nationalistic tones and concluded with these words: "Apple trees will blossom on Mars. Ours. Russian!" Anachronisms apparently abound in all arenas.

Pasadena—Following the loss of *Mars Observer* in August 1993, NASA organized several teams to determine the causes of failure and to investigate the question of a reflight or follow-on mission. At the time we go to press, the conclusions of the teams dealing with the spacecraft failure are not yet available.

As for recovering from the loss of *Mars Observer*, emphasis was initially put on a quick reflight, either with a second *Mars Observer* spacecraft, built from spare parts, or with a smaller and less costly defense satellite being developed by the Ballistic Missile Defense Organization (BMDO).

After an intensive one-month review, it was decided that the 1994 mission wasn't feasible due to a combination of financial, technical and schedule issues, and that efforts should be concentrated on 1996.

Planetary Society officers Carl Sagan and Bruce Murray were made part of the special team consulting with JPL about the proper recovery plan. It is still too early to say definitely what NASA will do. A broad range of possibilities is being considered as to how to meet *Mars Observer* objectives and for the whole US Mars program, from 1996 to the turn of the century.

Louis D. Friedman is Executive Director of The Planetary Society.

News and Reviews

by Clark R. Chapman

The *Magellan* mission began as a gleam in someone's eye two decades ago. Somehow, it gained real funding (called a "new start") during the budget-cutting decade of the eighties, and actually got launched toward Venus.

Then, as chronicled by veteran science writer Henry S.F. Cooper, Jr. (*The Evening Star,* Farrar Straus Giroux, 1993), *Magellan* faced two continuing threats. One was mechanical or electronic failure of the complex, remote-controlled machine, operating millions of miles from the nearest mechanic. The second was the equally omnipresent threat of funding cuts, which can kill a mission as surely as hardware failure.

The hapless *Mars Observer*—the only other NASA planetary mission to get securely out of the starting gate in the 1980s—fell victim to the first threat. And *Magellan,* too, faced repeated crises of "loss of signal." But *Magellan* did eventually phone home, and clever engineers found work-arounds that let the *Magellan* team sleep more easily at night as the mission progressed.

More relentless were shortsighted Washington budget cutters, focused on doing things flashily and cheaply rather than on capitalizing on investments and on completing a project well. For artificial accounting reasons, *Magellan*'s "primary" mission was defined as preparing a single map of Venus through its clouds. Making a gravity map and searching for ongoing geological activity had been left to the "extended" phase of the mission—just as Uranus and Neptune were encountered during the "extended" phase of *Voyager*'s mission.

The Continuing Scientific Drama

By the end of Cooper's narrative, most of *Magellan*'s scientists and engineers had been laid off or reassigned, but the spacecraft was valiantly attempting part of its extended mission on a shoestring budget. Even when *Magellan*'s transmitters fall forever silent, there will be much left to tell about *Magellan*'s unveiling of Venus. The exquisite maps of our neighboring planet will continue yielding secrets to researchers for years to come—provided, of course, that funds don't dry up entirely.

Cooper's book reads like Volume 1 of a two-volume work. Yet I suspect that Volume 2 will never be written, even if *Magellan* research continues. Cooper, after all, has chronicled NASA planetary missions before, in *New Yorker* articles and in several books, but neither he nor other science writers have written much about the continuing progress of planetary research: the insights gleaned years or decades after the exciting missions have flown.

Identifying With *Magellan*

In reading *The Evening Star,* I think I sense why there is such focus on encounters. Cooper's major topic is the ever-evolving interplay between data and hypothesis, as the multidisciplinary *Magellan* scientists struggled to learn about a new world from a sudden, enormous data-dump. Yet the ongoing drama that serves as the book's backbone, and gives it the feeling of a novel, revolves around the dangers to the spacecraft and its mission. *Magellan* itself is the prime character, and it was continually in jeopardy. Whether the threat came from a software glitch, faulty hardware or an official in NASA's Office of Space Science, Cooper is at top form portraying *Magellan* engineers as Scotland Yard detectives, saving the mission from predators.

Despite excellent metaphors and turns of phrase, Cooper's handling of the scientific drama is less convincing. Maybe I'm wrong. I cannot read the science objectively, since I merge what I already know—as a practicing planetary scientist—with Cooper's account. For me, Cooper's writing works wonderfully well. But a neophyte to Venus, I suspect, will get hopelessly lost amid the ever-changing hypotheses of the *Magellan* geophysicists. (Some pictures would surely help any book about a planetary imaging project; there are none in this book.)

I fear that Cooper is himself struggling with his admittedly difficult scientific topic and, therefore, occasionally falls short. For me, the major venusian mystery revealed by *Magellan* after a few months of mapping concerned the remarkable "freshness" of nearly all the craters on Venus. This key geological observation continues to fuel the major scientific debate about Venus: Did the planet undergo a sudden, fundamental change, or oscillation, several hundred million years ago in how it gets rid of its internal heat? Yet Cooper senses the topic's importance belatedly: He introduces it, obscurely, less than 40 pages from the end of the book. However, he devotes many pages to the more superficial (and inevitable) cases when the cold, hard facts from *Magellan* debunked several fleeting, speculative theories about Venus.

Maybe the intellectual drama of science is just too difficult to prop up unless it is accompanied by the more immediate appeal of an ongoing mission of exploration. As a practicing planetary scientist, I would like to think that the trials and tribulations of my world of research would be interesting fodder for a popular writer. But when the best of them (and Cooper is) needs the harrowing thrills of a spacecraft encounter to sustain his story, I think my wishes may be in vain.

Clark R. Chapman understands the exhilaration of a planetary encounter, and has written a not-yet-published book on Voyager*'s encounter with Neptune.*

Society News

Making Space for Developing Countries

Scientists from all over the world attended the United Nations Workshop on Basic Space Sciences for Developing Countries October 18–22, 1993, in Lagos, Nigeria.

Cosponsored by The Planetary Society and the European Space Agency, this third annual workshop focused on how space science and its associated technologies can be useful to developing countries. The workshop provided an opportunity for scientists from African countries to interact with colleagues from Europe, Asia and the Americas.

To maintain this interaction, a consortium of groups, including the UN and The Planetary Society, is proposing extending the science Internet—the electronic communication link for many scientists—to Africa. Planetary science applications will be the basis for this pilot electronic communications project. *—Christopher P. McKay, NASA Ames Research Center*

Washington, DC: The Space to Be

In July 1994, Washington, DC, will be the place for Planetary Society activities that celebrate two historic occasions—the 25th anniversary of the *Apollo 11* Moon landing on July 20 and the expected collision of comet Shoemaker-Levy 9 with Jupiter, an event that will be observable from Earth over a five-day period from July 19 through July 23.

To coincide with these events, The Planetary Society has organized a tour of the District of Columbia area for Society members, families and friends July 16–23, 1994. Tour members are guaranteed tickets to Society activities that will celebrate the *Apollo 11* anniversary and monitor the comet's collision with Jupiter.

The tour group will also attend private lectures on the comet and on other planetary topics. And tour members are scheduled to visit many of the space-related and historic sites in the Washington area, including the National Air and Space Museum, NASA Goddard Space Flight Center and George Washington's Mount Vernon home.

For a tour brochure, call Sam Shah at Advanced Travel, 1-800-248-0388, or write to Cindy Jalife at The Planetary Society, 65 North Catalina Avenue, Pasadena, CA 91106. Advanced Travel will also be able to help you with airline reservations.

Tour space is limited, and discounts are available for early reservations. For those considering travel to Washington, DC, for the public events, but not the tour, Advanced Travel can also help you with hotel accommodations. *—Susan Lendroth, Manager of Events and Communications*

Seeing Planetary Society Stars in Anaheim

For the fourth year in a row, The Planetary Society will present a series of special sessions at the National Science Teachers Association's annual convention. Cosponsored by the Society, the 1994 convention will be held in Anaheim, California, March 30 through April 2.

The Planetary Society's sessions will be held on Friday, April 1. David Levy, one of the co-discoverers of comet Shoemaker-Levy 9, and planetary scientist David Morrison will discuss the comet's upcoming collision with Jupiter. Michael Klein, a scientist at the Jet Propulsion Laboratory, will examine the search for planets around other Sun-like stars.

Also present will be Robert Staehle of JPL, speaking about the Pluto mission; science fiction author Larry Niven, discussing the CD-ROM library of science fiction being launched to Mars; and Louis Friedman, Executive Director of The Planetary Society, who will discuss the Russian rover and the fascinating technology of telepresence.

For a registration packet, call The Planetary Society at 1-800-969-MARS, or write to NSTA Convention at Planetary Society headquarters. *—SL*

Memorial to the First Astronomer Astronaut

Karl Henize, scientist and explorer, was the first astronomer of any nation to be chosen as an astronaut. His selection seemed then to indicate that fundamental science would be an important part of the US human space program. Henize is the latest of a number of astronauts, astronaut candidates and space scientists to lose their lives in exploration—often on inaccessible mountains, as close to the planets as they were able to climb. They were willing to take risks in the cause of exploration, space program or no space program. It is a pity that the human space program of the US and other nations no longer explores, no longer visits other worlds, no longer provides an opportunity for brave explorer-scientists to blaze new trails for the human species. Fittingly buried on his last mountain, Karl Henize will be sorely missed. *—Carl Sagan, President. (Memorial read at a service in Houston for Henize, who died while scaling Mount Everest on October 5, 1993.)*

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Questions and Answers

Could those mysterious spokes that appear in Saturn's rings be attributed to nothing more than a "stroboscopic slip effect," similar to the way the wagon wheels in a Western film beat in time with the movie camera's shutter speed to give an illusion of the wheel slowing down or even reversing?
—Alistair Murch, Worthington, United Kingdom

Before I answer your question, let me give you some background. *Voyagers 1* and *2* discovered a new form of brightness variation in the main rings of Saturn. These radially elongated, fuzzy-looking features appeared dark against the bright rings. They quickly got the name "spokes" because they seemed to rotate like the spokes of a wheel. Shortly afterward, when *Voyager* viewed the rings from a different angle, the spokes appeared brighter than the background rings. Also, we then saw that they were actually wedge-shaped, being narrowest at the location where ring material orbits at the same rate as the planet's magnetic field.

These changes in relative brightness, and the observation that the spoke structure was tied to the motion and strength of Saturn's magnetic field, led us to believe that they were regions of abundant micron- and submicron-sized ice grains, probably puffed up off the surfaces of the normal centimeter- to meter-sized icy ring particles. Such small particles are easily affected by otherwise tiny magnetic forces, and their light-scattering properties agree with the observations. Several years after *Voyager*'s flyby, it was suggested that such tiny particles could be produced in the sporadic fashion observed, with associated electrostatic charging, by interplanetary debris hitting the rings.

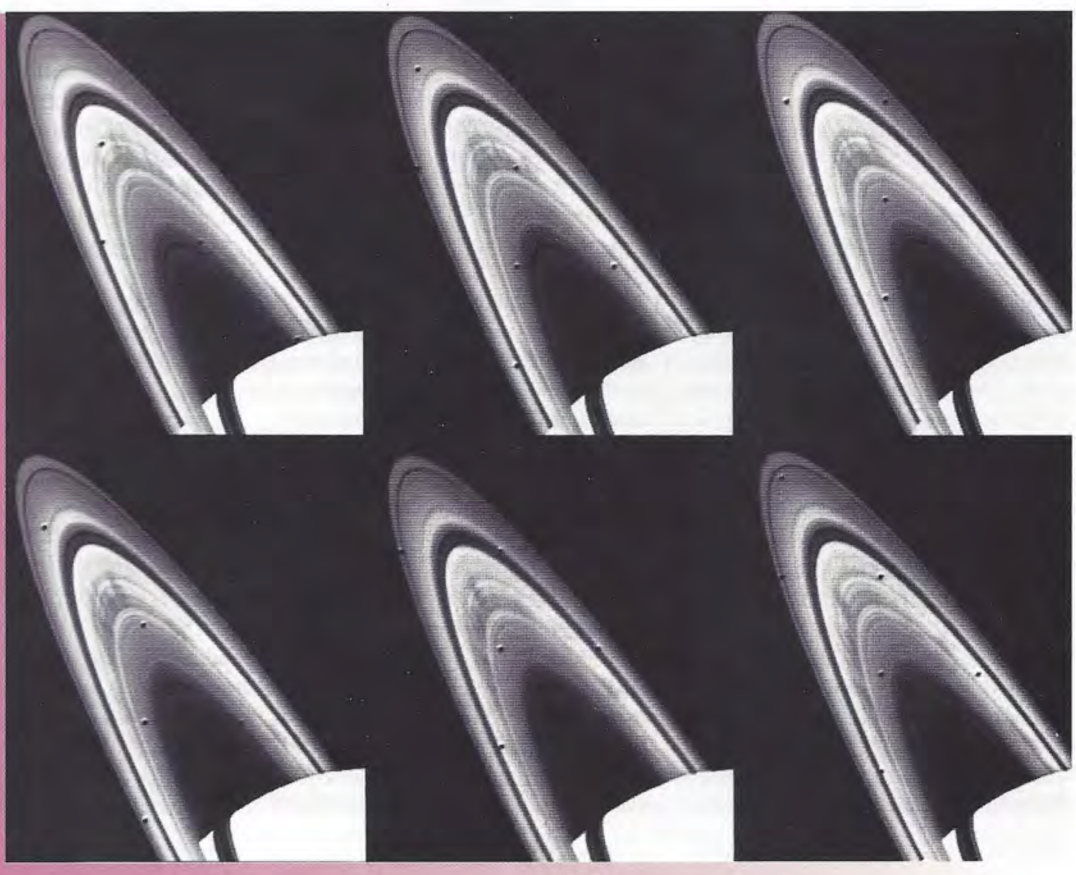
The meteorite impact trigger idea is supported by the fact that most of the spoke-creation episodes seem to occur in the region where the impact velocity and flux (the rate of particle flow) would be the highest. The huge cross section of the rings provides an impact rate that could agree fairly well with the observations, although the flux of projectiles is something we don't know much about.

Another theory describes a form of magnetic instability that can occur as a result of a meteorite impact, or even an unrelated fluctuation in the plasma surrounding the rings.

A strobe light works by freezing

One of the most surprising discoveries of Voyager 1's 1980 encounter with Saturn was the dark "spokes" that seemed to rotate like the spokes on a wheel. In this sequence of images, you can follow their progress around the planet. The spokes are probably tiny ice grains, knocked loose by meteorite impacts on ring particles, which are caught up in Saturn's magnetic field and accelerated around the planet.

Images: JPL/NASA



the motion of a very rapidly moving object; for repetitive patterns such as the spokes of a wheel, the speed can be measured by adjusting the light's flash rate to mimic the time it takes for one spoke to advance exactly to the position of another. This effect would not apply here because sunlight has no such regular (or even irregular) flickering. Neither are the *Voyager* cameras susceptible to this sort of effect.

There is surely a lot that we don't understand about Saturn's spokes and about the rings in general. When *Cassini* arrives at Saturn in 2004, it will observe the flux of interplanetary material with its dust detector, observe the changes in the magnetic fields near the rings with charged-particle detectors, and observe the structure, formation, color and evolution of the spokes. It will discover whether the distribution of spokes varies with time and tilt of the rings, as might be expected based upon a meteoroid impact hypothesis.

Cassini will also answer many other questions about the rings: how the composition varies from dark, grayish material in the C ring and Cassini Division to bright, reddish material in the B and A rings; whether small moonlets reside in the many empty gaps in the rings (other than the one 10-kilometer object discovered recently in the A ring's Encke gap); whether new ring features have appeared or whether some of the features *Voyager* saw have since evolved into different forms.
—JEFF CUZZI, *NASA Ames Research Center*

Does Mars have an ozone layer similar to that of Earth? If so, are there fluctuations in the layer (presumably due to natural causes) similar to those resulting in the ozone hole(s) currently causing so much concern on Earth?
—Mike Cleary, Jefferson City, Missouri

Mars' ozone has been studied from Earth-based observatories and from Russian and American spacecraft, most notably *Mariner 9*. Mars does in fact have an "ozone layer" at equatorial and midlatitudes, much as Earth does.

In those regions, Mars' ozone concentrations are highest at an altitude of around 30 to 40 kilometers (19 to 25 miles), with a maximum concentration of about 0.5 parts per million (ppm). For comparison, ozone concentrations on Earth reach a maximum of about 5 ppm. However, the vertically mixed amount of ozone is many, many times less than it is on Earth.

Hence, while ozone on Earth shields the surface from much of the Sun's harmful ultraviolet radiation, the ozone on Mars does not. Furthermore, while the ozone in Earth's stratosphere exerts a strong control on the temperatures there, Mars' ozone exerts only a negligible control on the planet's atmospheric temperatures.

At Mars' poles in winter, ozone does not form a "layer," since it also exists in high quantities near the surface. The vertically integrated amount of ozone is higher at the poles than at equatorial latitudes in winter. Thus, ozone on Mars fluctuates much more than what we've observed on Earth, but for different reasons.

Earth's ozone hole is related in part to human-made chemicals that are not present on Mars. There, concentrations are more strongly influenced by the amount of water vapor, and the wide variability of water vapor on the planet results in a large fluctuation in the amount of ozone.

This explains why ozone on Mars is more abundant at the very cold wintertime poles, where water vapor is frozen out of the atmosphere. In fact, observations by *Mariner 9* in 1972 showed that ozone rose and fell in conjunction with the passage of meteorological cold fronts, due in part to the reduction in water vapor in colder air and in part to the obscuration of ozone by clouds and dust.

Our group is proposing to NASA that a balloon-borne ozone detector be sent to Mars to study this variability more closely, as a possible Discovery-class mission.
—B. LEE LINDNER, *Atmospheric and Environmental Research, Inc.*

Factinos

Examining the role of bubbles in the origin of life on Earth is one of the newest approaches to solving the scientific mystery that is probably second in importance only to the puzzle of how the universe itself began.

No one is saying that bubbles might explain everything. But a new theory receiving close attention suggests that the multitudes of bubbles forming on the surface of the primordial seas may have collected chemicals and concentrated them for synthesis into complex molecules. Eventually, through multistage reactions constantly repeated by uncounted generations of bubbles, the molecules grew in size and ambition, until they were ready for the transition to living, reproducing cells.

Louis Lerman, a geophysicist from Lawrence Berkeley Laboratory in California, is the originator of the concept. Biologists have said that the concept seems sound and is based on well-established physical principles, and is certainly worth detailed study. Sherwood Chang, a specialist in the origin of life at NASA's Ames Research Center, said, "Clearly the ocean-atmosphere interface is a dynamic environment worthy of much future study and simulation as a site for chemical evolution."

One attraction of the new hypothesis is that it offers a mechanism for a rapid chemical evolution. "Lerman is suggesting how the primordial soup might have been stirred up," said James P. Ferris, a chemist at Rensselaer Polytechnic Institute in Troy, New York, and editor of the journal *Origins of Life and Evolution of the Biosphere*.
—from John Noble Wilford in *The New York Times*

For the first time, scientists have detected polycyclic aromatic hydrocarbons, an important family of organic molecules, in interplanetary dust. This dust may be some of the oldest matter in the solar system. The discovery gives weight to the theory that tiny dust particles from outer space helped seed Earth with the chemicals necessary for life to begin.

Two research teams collaborated on analyzing the dust, which was collected by a NASA aircraft. At Washington University in St. Louis, Robert M. Walker and colleagues measured the abundance of different isotopes of the same element and concluded that the dust did originate outside Earth. At Stanford University, a group including Simon J. Clemett and Richard N. Zare first vaporized, then ionized organic molecules in the dust. After using a mass spectrometer to sort the ions, the researchers concluded that they had indeed detected polycyclic aromatic hydrocarbons.
—from Ron Cowen in *Science News*

Journey to the Planets This Winter!

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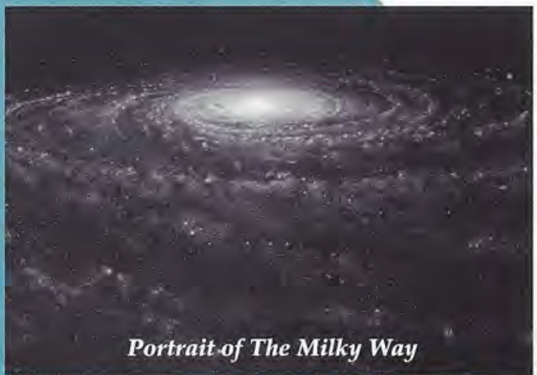
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Attention Teachers:
If you are Planetary Society members, submit your order for any item offered on these pages on your school letterhead and enjoy a 20% discount!

Stereoscopic vision will be a valuable tool for navigating the rover on Mars. During the August 1993 telepresence/virtual reality tests performed while the rover was in Kamchatka, the American team used a Silicon Graphics workstation and specially designed glasses to view the rover's images in three dimensions. We can't reproduce that high-technology effect on the page of a magazine, but this is an attempt to partly simulate the experience for all our members.

This is one of the images from the stereo pairs taken by the rover. Hold it about 30 centimeters (12 inches) from your face and stare at the left image with your left eye and the right image with your right eye. It might help to hold a piece of cardboard upright between the images. As you stare, a stereoscopic image should appear in the space between the two printed images.

Fortunately, when we attempt to drive the rover across Mars, we will have computer tools to make stereoscopic vision easier to achieve. And this new technology should significantly advance our abilities to explore other worlds. Image: Mars Rover

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